4.5 Estimating Evacuation Time Components: Lessons from Nuclear Power Plants, Hurricanes, and the First World Trade Center Bombing

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Protective actions in response to environmental threats can be defined by a series of stages—detection/warning, psychological preparation, logistical preparation, and protective action selection/implementation. In this formulation, which Lindell and Perry (2004) call the *Protective Action Decision Model* (PADM), detection is defined by environmental cues received directly from the environment, whereas warning is obtained from authorities, news media, and peers (friends, relatives, neighbors, and coworkers). Psychological preparation consists of predecisional processes, decision making, and information seeking. The predecisional processes are exposure (being in a position to receive threat information either from the environment or from other persons), attention (noticing the information that is available), and interpretation of the environmental cues or comprehension of the warning messages. Decision making consists of a series of stages of conscious information processing. The first stage is risk identification, which seeks to answer the question "Is there a real threat?" The second stage is risk assessment, which seeks to answer the question "Do I need to take protective action?" The third stage, protective action search seeks to answer the question "What can be done to achieve protection?" The fourth stage, protective action assessment, seeks an answer to the question "What are the merits of alternative methods of protection?" The fifth stage, protective action selection seeks to answer the question "What is the best method of protective action for this situation?" and the last stage, protective action implementation asks the question "Does protective action need to be taken now?"

It is frequently the case that those at risk do not know the answers to these questions, so information seeking routines are initiated. The first of these is information needs assessment, which seeks to answer the question "What additional information do I need?" The second stage, communication action assessment/selection seeks to answer the question "Where and how can I obtain the needed information?" The third stage, communication action implementation seeks to answer the question "Do I need the information now?" These stages of decision making and information seeking are followed very systematically by some people, heuristically by others, and (rarely) not at all by still others. Defective information seeking and processing is caused by incorrect schemas about the hazard and protective actions (e.g., failure to anticipate the future consequences of present conditions), faulty assumptions (e.g., incorrectly assuming that people will panic if they are warned), or emotional overload.

Once a protective action is selected, logistical preparation is often needed before implementation. This can include gathering persons who will evacuate as a group, packing any essential items, protecting personal property that can't be moved, and securing the location against intrusion.

The model can be represented as a decision tree or network of nodes (answers to questions) and arcs (information processing activities). Individuals differ in the paths they take through the

network, the amount of time taken to traverse each arc, and the number of iterations in decision making and information seeking loops. Transfer of organizational roles and training from other situations can facilitate response.

There are a number of critical elements to the PADM. The first one is that threatened populations respond as social units, not as isolated individuals. The second is that people rarely are satisfied that they already know enough to protect themselves, so they seek information and reassurance from others. A third element is that information sources often provide conflicting information, which is difficult to reconcile because of lack of complete credibility by any single source. A fourth element is that people often have very little accurate information about protective actions and correct information is rarely contained in warning messages. A fifth element is that people independently examine official protective action recommendations (including the absence of any official recommendations) and make an independent evaluation of the situation that might result in their taking protective action even though authorities believe that this is not needed (e.g., shadow evacuation). Finally, people can iterate through the stages of decision making and information seeking, thus delaying adaptive responses.

Application to nuclear power plant and hurricane evacuations

The time required for a *single* household to evacuate is the sum of the times required to receive a warning, prepare to evacuate, travel on collector routes to the primary evacuation route, wait for access to the primary evacuation route, and travel on the primary evacuation route. The time required for *all* households to initiate and evacuation is defined by distributions of the individual evacuation time components. Empirically based trip generation time (TGT) distributions for risk area residents can be generated by combining the times required to receive a warning, and prepare to evacuate.

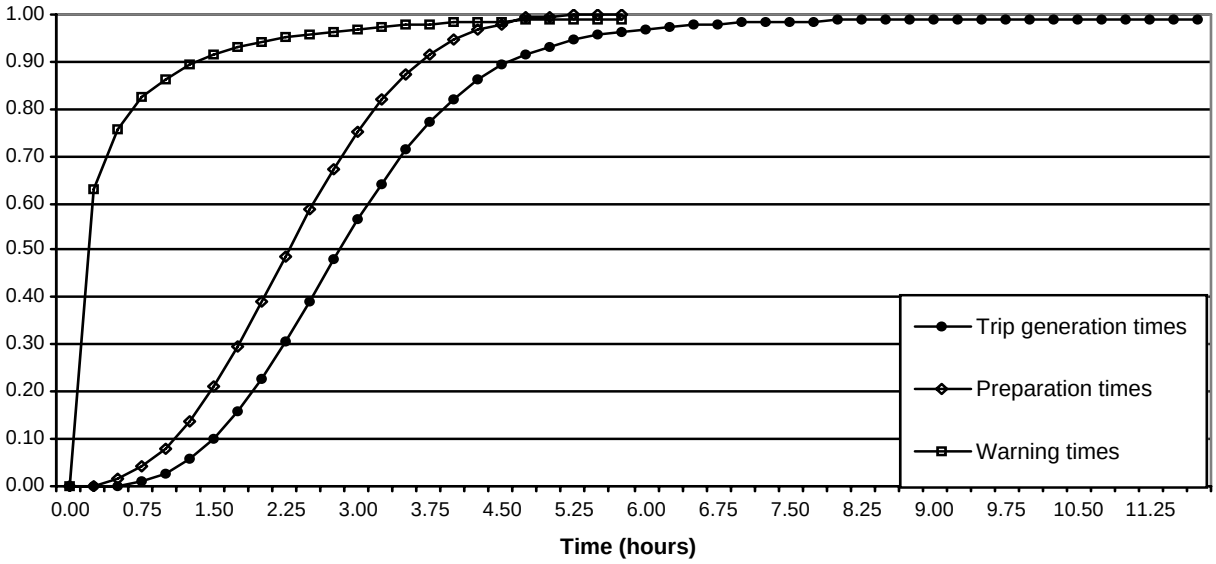

Figure 1: A TGT distribution for households

Travel time from home via collector routes to the primary evacuation route is a function of the distance from the home to the primary evacuation route, and the average travel speed on the collector route. The time required for evacuating vehicles to wait for access to the primary evacuation route can be computed by means of four recursive equations.

$$\Delta D_t = \Delta A_t + Q_{t-1}, \quad (1)$$

where ΔD_t is the incremental traffic demand at time t, ΔA_t is the incremental flow on arterial/collector routes at time t, and Q_t is the size of the queue awaiting access to the primary evacuation route at time t (Q_0 is assumed to be zero). Moreover,

$$P_t = \text{Min}\,(\Delta D_t, C), \quad (2)$$

where P_t is the primary evacuation route's traffic flow at time t, and C is evacuation route capacity. Next,

$$E_t = P_t + E_{t-1}, \quad (3)$$

where E_t is the total number of vehicles that have entered the evacuation route system through time t. Finally,

$$Q_t = \Delta D_t - C. \quad (4)$$

These four equations are solved repeatedly at successive time intervals $t \geq 1$ until all transients have entered the primary evacuation route, and all households intending to evacuate (compliant evacuees + spontaneous evacuees) have entered the primary evacuation route.

Application to Building Evacuations

Data from the first WTC bombing show that this ambiguous situation elicited an orderly process of information seeking that tended to delay evacuation (Aguirre, Wenger, & Vigo, 1997; Prater, Wenger & Lindell, 1997; Wenger, Aguirre & Vigo, no date). Consistent with emergent norm theory, the information seeking (milling) process was influenced by pre-existing social relationships. Moreover, though there was a widespread and increasing perception of danger and some of the conditions for panic existed, the evacuation was orderly. This similarity in occupant behavior to that displayed by community residents in other types of disasters suggests that building evacuations in response to threats or acts can also be explained by Lindell and Perry's (2004) PADM. There has been a considerable amount of research that has studied the relationship between detection/warning and evacuation. However, there has been very little research to date that has attempted to characterize household preparation times or the variables that account for differences among households in their preparation times. The available studies have found few, if any, reliable predictors of this evacuation time component (Aguirre, Wenger, & Vigo, 1997; Lindell & Perry, 1987; Lindell & Perry, 1992; Lindell & Perry, 2004; Lindell, Prater, Sanderson, Lee, Zhang, Mohite & Hwang, 2001; Lu, Lindell & Prater, 2004; Sorensen, 1991; Tierney, Lindell & Perry, 2001).

However This is because social units within a building are defined more ambiguously than households within a community, employers can exercise more control over employees' threat responses than public officials can exercise over community residents, and occupants' perceptions of alternative protective actions in buildings are likely to be different from residents' perceptions of the available protective actions in communities.

Although the data from the first WTC bombing are consistent with the PADM, there are three major reasons why further research is needed to determine the correspondence between community evacuations and building evacuations. First, the social units within a building are defined more ambiguously than households within a community. Alternate bases for defining social groups include physical structures (buildings, floors, office complexes) formal organizations (companies, divisions, branches, sections), and informal organizations such as friendship groups. All three of these bases can lead to the same patterns of social grouping, thus reinforcing them, but need not necessarily do so.

A second difference from community evacuations is that employers can exercise more control over employees' threat responses than public officials can exercise over community residents. This would decrease the independence of response that is often seen in community evacuations.

A third difference from community evacuations is that perceptions of alternative protective actions are likely to be different in buildings. One example is that capacity constraints on evacuation routes are likely to be more apparent within buildings than in communities. In addition, occupants are likely to perceive the costs of building evacuation to be lower than those of community evacuation because they are abandoning the employer's property, not their own. Finally, the safety risks of sheltering in-place are likely to be more apparent within buildings—especially high-rise buildings—than in communities.

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